Ground Motion and Cultural Noise R & D Program

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Excerpts from MAC_ June 03_ Report

• The small attenuation of noise between tunnels or along one tunnel,…emphasizes the need to pay close attention to noise sources within the klystron tunnel.

• Sometime the Committee would like to hear a presentation on the strategy being considered besides selecting sites that are inherently quiet, or perhaps selecting technology more tolerant of vibration.

• Strategies that might include specifying equipment with very low source vibrations, designing cooling with very low source vibration, using standard equipment in the conventional facility but connecting to the facility through isolators, making the beam support design less susceptible to externally exited vibrations, etc.
Goals and Objectives

- To estimate and to mitigate the effect of cultural noise sources on the focusing components of the main linac
- To characterize the major vibration sources in the klystron/service tunnel
- To characterize their transmission paths
- To estimate the response of the focusing components of the main linac from these vibration sources
- To assess the estimated response relative to the vibration criteria (goals), and based on that assessment—
  - To mitigate vibration effects
  - To evaluate alternatives, tradeoffs
- To better define concept design requirements
Select a Location (Representative Site)  
Good Geology and Quiet

Far-Field Excitation  
(Ambient Ground Motion Measurement)

Geotechnical Studies  
(Soil/Rock Classification)

Attenuation Characteristics of Soil/Rock

Estimate Near-Field Excitation  
(At Their Footings)

Estimate Technical Foundation Vibration  
(Response to Near and Far Fields Sources)

Acceptance Criteria

Adopt as a Concept Design Requirement

Yes

No
Where are we?

- We have measured ambient ground noise (natural, far-field) for the NLC representative California sites
  - CA-127, CA-135, Copper Mountain and Logan Ridge (CA-135)
- We have performed vibration tests of the major sub systems and have identified the major (cultural, near-field) vibration sources
  - LCW cooling system, rotating mechanical and electrical equipment
- We have characterized the vibration transmission between two parallel tunnel in similar geological formation as in CA-sites
  - Attenuation between the tunnels is very low
- We have prepared the vibration and the stability parameters for the cold and warm machines
  - Vibration budget for the cultural (near-field) sources is very tight
Introduction to science needs

- Assumptions:
  - The total beam jitter at the IP is 50% of the beam size, with the following uncorrelated contributions:
    - 30% from the main linac, 30% from the beam delivery, 25% from the final doublet, and with 15% injection jitter, RSS is ~50%
  - Assuming the above jitter budget:
    - The vertical vibration of the linac quadrupoles needs to be less than 12 nm above several Hz
Beam Housing Foundation Vibration Criteria

- **Vibration Criteria at the invert of Beam Housing**
  - The RMS value of the imported (i.e. added) broadband vibration integrated above 3 Hz should be less than a factor of two (2) times the pre-existing ground vibration amplitude, excluding the resonant “spike” vibrations synchronous with collider repetition rate.
  - With the resonant spikes included, the RMS amplitude above 3 Hz should be less than a factor of three (3) times the pre-existing ground vibration amplitude.

*It's assumed that the pre-existing RMS value of the vertical component of ground vibration amplitude is less than two nanometers integrated above 3 Hz.*
Sites are on suitable/stable geology for tunneling.

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Sites are very quiet, with negligible contribution from cultural noise
Ground-exited vibration due to ambient, facility-transmitted vibration must be $< 2 \text{ (LSDS)}$

The RMS acceleration resulting from each narrowband excitation in the frequency band:

- $0.1 \text{ Hz} < f < 1 \text{ Hz}$ must be less than $2.4 \times 10^{-7} \text{ m/sec}^2$,
- $1 \text{ Hz} < f < 50 \text{ Hz}$ must be less than $5 \times 10^{-4} \text{ m/sec}^2$, and
- $f > 50 \text{ Hz}$ must be less than $3 \times 10^{-9} \text{ m/sec}^2$ at Laser & Vacuum Equipment Area.
Results of the vertical acceleration measurements in LVEA at LIGO Hanford – Jan. 98

HVAC off, only circulating pumps on, and HVAC on

The HVAC system causes broad band motion of the slab in excess of 5 times LIGO Standard above 5 and below 50 Hz. With the HVAC system off, the building is remarkably quite.

The narrow band excitation between 1 to 50 Hz is less than $5 \times 10^{-5}$ g (rms) allowed in the spec.
Next Linear Collider – MAC Dec. 2003

NIF-SPIKE-NEW.PDW
Based on 0.03g Analysis Unbalance
New Equipment

PSD Acceleration Amplitude (g^2/Hz)

0.0024 micron = 2E-11 g^2/Hz @ 60 Hz
0.003 micron @ 60 Hz

Top of Foundation
Free-Field

0.003 micron @ 30 Hz

0.003 micron @ 15 Hz

Frequency (Hz)
NIF Vibration Measurements – Conclusions:

• The general foundation PSD measurements are much lower than the predicted foundation PSD envelope

• The overall RMS displacements at the laser equipment foundations are one tenth of the overall RMS displacements of the design PSD level

• The spike amplitudes are within allowable limits
Next Linear Collider – MAC Dec. 2003

- Quadrupole Electromagnet
- Eight 60 cm Accelerator Structures @ 6 meters quad-to-quad
- 5 x 2 Staggered Diagonal SLED-II
- Double Rack
- Two Klystron 2 Packs & Modulators
- Panel & Transformer
- LCW Pump Skid
- 4 Modulator 8 Klystron Power Transformer
- @ 100 m

4.5 Meters ID + 6 Meters

Penetration Section

- SLED-II
- Cable & Tray
- Conduits
- Transformer
- Rack
- Klystron
- Cooling
- Modulator

Penetration
- Waveguide
- Magnet
- Beam Line
- Pedestal

~3 meters

Sprinkler Head

Drain
Lessons Learned (LIGO & NIF Projects)

- Major rotating equipment
  - Use skid with 3 Hz spring isolators
  - Add concrete to the skid base
  - Use Vane axial HVAC Fans
  - Use Highest operating speeds
    - 30 Hz or higher
    - Single shaft pump & motors
  - Conduct steady state vibration prediction tests and analyses
    - Utilize a proven 3-D computer modeling program for dynamic soil-structure interaction problems (e.g. SASSI)

- Flow induced vibration
  - Provide pipe-support isolators
  - Minimize pipe span lengths
  - Minimize flow velocities in pipe, hoses
    - Ideal flow velocity is 1.0 feet/sec;
    - Nominal flow velocity is 3.7 feet/sec;
    - Maximum flow velocity is 14.8 feet/sec
• The attenuation in tunnel A at 48 ft and 95 are similar to attenuation at 0 ft (~39 ft apart) and 100 ft in tunnel B, respectively
  – This indicates that the two tunnels are experiencing similar vibration levels at similar distance
• The wavelength at 10 Hz is ~ 300 to 400 ft
  – Since the tunnels are only ~39 ft apart, the long wavelengths cannot be represented by simple transmissibility curve

Ground shear Velocity=3000 to 4000 ft/sec
Example:

- Weight of rotating part of motor and pump on the skid, \( W = 300 \) lb
- Operating Frequency, \( f = 3600 \) RPM (60 Hz)
- Unbalanced force for rotating part = 0.03 to 0.1 g
- Skid is mounted on 3 Hz spring isolation

Estimate of vibration at Beam Housing Invert:

- Force applied at the skid, \( F = (300 \) lb) (0.1) = 30 lb
  \( F = (30 \) lb) (4.448 N/lb) \approx 134 \) N
- From graph, Mobility @ 60 Hz, \( V = 0.0007 \) cm/sec/N
- Displacement, \( D = \frac{V}{(2\pi f)} = 0.0007/(120*3.14) = 1.856 \) (10E-6) cm/N = 18.56 nm/N
- Attenuation from source to 40 feet = 0.6
- Thus, Displacement Amplitude @ invert of Beam housing, \( A = 0.6 \) (18.56 \( \mu \)m/N) (133.5 N) \approx 1487 \) nm
  \( A (\text{max}) \approx 1.5 \) \( \mu \)m ( Mounted without spring isolator)
  \( A (\text{min}) \approx 0.5 \) \( \mu \)m ( Mounted without spring isolator)
- With 3 Hz spring isolators @ 60 Hz vibration:
  Attenuation of Isolators \((3/60)(3/60) = 0.0025\)
  \( A (\text{max}) = (0.0025) (1487) \approx 3.7 \) nm
  \( A (\text{min}) = 0.3 \) (3.7) \approx 1 \) nm

Above Figure is an upper bounds mobility function at 20 feet from the vibration source.
What have we learned so far?

• The dominant vibration sources effecting the focusing component of the main linac are:
  – Flow induced vibration from LCW cooling system
    • A pressure fed LCW cooling system can induce ~2.5 times above the vibration acceptable level on quadrupole magnets due to mechanical coupling, with structures, hoses, pipes (Ref: tests carried out using LCW cooling at NLCTA compared with gravity fed LCW test carried out in Collider Hall)
      – Characteristics of the tested magnet were not similar to the magnets that are proposed for the NLC magnets
  – Ground transmitted vibration from major vibration sources in support tunnel, such as rotating mechanical and electrical equipment
    • Vibration induced through ground by rotating mechanical and electrical systems can easily exceed the vibration budget, if they are not properly isolated
• Each of the above vibration sources can easily bust the vibration budget, if we do not pay attention to their details and if we do not properly isolate them
What should be done next (Strategy)
To initiate an integrated analytical/experimental vibration R & D program

- To utilize a proven 3-D computer modeling and analyses program for dynamic soil-structure interaction problems (e.g. SASSI)
- To set-up a vibration test facility
  - Testing area should be similar in geological condition and configuration to the two tunnels arrangement for the NLC
- To conduct steady state vibration tests to characterize vibration transmitted from source to the quadrupole electromagnet through ground, water and mechanical coupling
- To assess the response of the quadrupole electromagnet from these sources relative to the adopted vibration criteria (goals), and based on that assessment:
  - Mitigate vibration effects by trying different options, tradeoffs
- To better define concept design requirements
Strategy (Analytical Approach)

• To retain service of a firm experienced in application of SASSI computer program
  – SASSI, a System for Analysis of Soil-Structure Interaction, developed by UC Berkeley
  – SASSI program has successfully been used to predict vibration response of critical area to major rotating mechanical & electrical equipment at NIF
• Develop a 3-D model of a segment of MTA tunnels (A and B)
• Perform analyses to predict response of the beam tunnel invert from cultural sources
• Calibrate the model by using MTA tunnel vibration test results
• Use the 3-D model for vibration trade studies and assessing different isolation options

A calibrated 3-D computer model of a segment of NLC tunnels is a useful tool for managing the vibration budget, as well as, for optimizing the design of support equipment
Strategy (Experimental Approach)

- Measure ambient ground noise (natural, far-field) at the De Kalb site
  - This effort is in planning stage (Fermi and NIU collaboration)
- Set-up a mobile test stand for LCW circulating system
  - Similar in configuration and vibration parameters as to the NLC
  - Provide a Variable Frequency Drive to perform number of desirable tests at different frequency level (Test procedure TBD)
  - Mount skid on 3 Hz spring isolators, fill skid with concrete, if necessary
- Testing area should be similar in geological condition and configuration to the two tunnels arrangement for the NLC
  - Magnet and LCW circulating system should be in separate tunnel and should be separated by about 40 feet
  - Locate a magnet coupled to a structure similar in dynamic characteristics to the one proposed for the NLC
- Conduct steady state vibration tests to characterize vibration transmitted from source to the magnet through ground, water and mechanical coupling
- Use the test data to calibrate 3-D computer modeling and analyses program (e.g. SASSI)
Next Linear Collider – MAC Dec. 2003

Where

- 748 Collider Housing-North Arc access
- Geological condition similar to CA representative sites as well as MTA tunnels
- Miocene sandstone (Shear velocity ~ 4000 ft/sec)

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LCW Cooling System
Just a few options

• Move major rotating mechanical and electrical vibration sources far away from the beam housing
  – This option was exercised prior to USLSG mandate in order to compare the cold vs. warm technology using a parallel tunnel arrangement
• Support rotating equipment on separate foundation decoupled by rubber isolation from the invert of support tunnel
  – Use polymer concrete with high damping, if necessary
• Specify custom made rotating equipment with very low unbalanced dynamic load (Redundant pairs cancel pitch & Roll)
  – This not only adds to initial cost, it also adds to the maintenance cost
• Mount skid on 1 Hz air bearing isolators (a costly proposition), instead
• Use a compound isolation system at the focusing components of the main linac
Recommendation

• To proceed with an integrated analytical/experimental vibration R & D program

• To establish an “Advisory Vibration Isolation Committee”
  – James M. Kelly (Professor in the Graduate School at the University of California at Berkeley)
  – Paul B. MacCalden (former Vice President and manager of Technology at Parsons, retired)
  – Nick Simos (our collaborator at BNL)